A comparison of the viability criteria developed for management of ESA-listed Pacific salmon and steelhead

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Twenty-seven evolutionarily-significant units (ESUs[1]) of Pacific salmon and steelhead are listed under the federal Endangered Species Act (ESA). The first phase of recovery planning following ESA-listing includes development of biological viability criteria for each ESU and the populations[2] within it. These biological viability criteria describe conditions that, when met, indicate a population or ESU is not likely to go extinct, and they are used for status assessments of the ESU (NMFS 2000). While viability criteria inform delisting criteria, they are not synonymous with delisting criteria as delisting criteria are based on both science and policy considerations (NMFS 2000). There are currently nine sets of viability criteria that have been developed for ESA-listed Pacific salmon and steelhead by different Technical Recovery Teams (TRTs) throughout the range of Pacific salmonids. This paper briefly describes the process through which viability criteria were developed, and outlines the similarities and differences among the nine sets of viability criteria, describing *what* was included in the criteria; not *why* analyses were included or excluded.

This review is part of a project focused on qualitative and quantitative comparisons of the viability criteria for ESA-listed Pacific salmon and steelhead. The motivation for this essay is to provide a summary and comparison of the viability criteria among ESUs. In addition, we hope that this summary and comparison will be useful when viability criteria are updated or developed anew in the future. Recovery plans and

[1] A distinct segment (population or groups of populations) of a Pacific salmon species that is substantially reproductively isolated from conspecific segments and represents an important component of the evolutionary legacy of the species (see Waples (1991)). Populations can be either independent or dependent. Dependent populations require immigration of individuals from surrounding populations for long-term persistence.

[2] A demographically independent group of fish

viability criteria for other species listed under the ESA are known to vary widely (Boersma et al. 2001), and there is currently no effort underway to standardize recovery plans for ESA-listed species. The differences among the recovery criteria for ESA-listed Pacific salmon and steelhead are likely small compared to the differences among the recovery criteria for the entire pool of ESA-listed species.

As an introductory paper, this essay does not contain much detail and, instead, focuses on developing a common language for understanding and comparing the criteria. Detailed summaries of the criteria are presented in a separate viability criteria summary table (See Viability Criteria Comparison Table). Other quantitative analyses are underway to assess the nature of the similarities and differences in viability criteria metrics. Insight gained from comparing and contrasting the criteria will help technical teams in designing approaches to evaluate viability and decision makers in interpreting and implementing ESA delisting criteria.

Analysis by domain

The National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) had a number of options for developing viability criteria for the 27 ESA-listed Pacific salmon and steelhead ESUs. The three main options for developing the viability criteria were to treat 1) each ESU independently, 2) all ESUs together, and 3) groups of ESUs together. Treating each ESU independently was not a feasible option due to constraints on time and the number of scientists to serve as technical advisors, and there was little biological reason to do so. On the opposite extreme, one set of viability criteria could have been developed for all ESUs. While such an all-encompassing effort could be efficient in terms of time and effort, doing so had a number of drawbacks. The listed ESUs include five species and span coastal and interior ecosystems from southern California to Washington's Olympic Peninsula. As such, these ESUs represent fish that have different life-history patterns, occupy different habitat types, experience different climatic and disturbance regimes, and inhabit locales within the center and edges of their species' geographic range (Salmon Recovery Science Review Panel 2002). For these reasons, the basic biology of the fish and the mechanisms that regulate them, such as ocean conditions and freshwater carrying capacity, are likely to vary. Furthermore, regional differences in data availability complicate the feasibility of developing a uniform analysis coast-wide. Several ESUs almost entirely lack the population-specific data that allow development of criteria tailored to the inherent productivity of individual populations. Finally, adequate involvement of local managers is challenging when such a coast-wide spatial scale is considered.

In order to better capture regional and local variation in environmental conditions and population dynamics, as well as take advantage of the local expertise of biologists, NMFS chose to convene technical teams that focused on several ESUs within biogeographically and politically coherent recovery domains – the middle ground between the two options discussed above. NMFS organized teams of scientists, called "Technical Recovery Teams" (TRTs), to develop viability criteria for eight groups of listed ESUs, called "domains" (Figure 1). Because multiple ESUs within a geographic region share common habitat, threats, and disturbance regimes (both natural and anthropogenic), there is sound biological reason to treat groups of ESUs together. Doing so also facilitates the involvement of local scientists in the development of the criteria and, in the Northwest, is consistent with the approach to develop locally-based recovery plans. However, when the TRTs were created, there was full recognition by all involved parties that having multiple independent TRTs might result in differences in viability criteria. NMFS recognized that their chosen approach amounted to launching an experiment in which several technical teams, given the same general guidance, were given freedom in developing analytical approaches. The balance between potential benefits—allowing multiple, creative processes to play out; and costs—inconsistency in results arising from relatively independent teams—in this approach is part of what we are examining in this work.

Composition of the Technical Recovery Teams

NMFS believes that it is critically important to base ESA recovery plans for Pacific salmon and steelhead on the many state, regional, tribal, local, and private conservation efforts already underway throughout the region. Local support of recovery plans by those whose activities directly affect the listed species, and whose actions will be most affected by recovery requirements, is essential. The process through which recovery plans were developed depends on policy decisions made by NMFS' Northwest and Southwest Regional Offices and differs between regions. In the Northwest, NMFS supports and participates in locally-led, collaborative efforts to develop recovery plans, involving local communities, state, tribal, and federal entities, and other stakeholders. In the Southwest, NMFS leads the recovery planning effort and involves several partner agencies and organizations in the process. TRTs are not the entities that developed recovery plans, but the TRTs did interact to varying degrees with those charged with developing recovery plans.

For each domain, the Northwest Fisheries Science Center and Southwest Fisheries Science Center convened and chaired a collaborative, multi-agency TRT to, among other activities, develop recommendations on biological viability criteria for ESUs and their component populations. The intent in establishing the TRTs was to seek unique geographic and species expertise, develop a solid scientific foundation for the recovery plans, and incorporate both federal and non-federal scientists in the recovery process.

Two other groups of scientists play important roles in the listing and recovery of Pacific salmon and steelhead. Biological Review Teams evaluate the status of ESUs and make technical recommendations that underpin listing decisions made by NMFS Regional Offices. The Salmon Recovery Science Review Panel, a group of non-federal scientists, was established to 1) review the core scientific approaches and elements of the recovery planning process developed by the NMFS, 2) ensure that well-accepted and consistent ecological and evolutionary principles form the basis for all recovery efforts, and 3) review the analyses and products of TRTs for scientific credibility and to ensure consistent application of core principles across ESUs and recovery domains. For example, the Salmon Recovery Science Review Panel recommended that the TRTs construct the simplest possible models for estimating abundance and productivity that still include the major mechanisms that drive population dynamics (Salmon Recovery Science Review Panel 2000).

Viable Salmonid Populations

Although NMFS encouraged the TRTs to develop regionally-specific approaches for evaluating viability, each TRT worked from a common foundation to ensure that the recovery plans they developed were scientifically sound and based on consistent biological principles. At the start of the recovery planning process, NMFS developed a conceptual approach for describing characteristics of viable salmonid populations (VSP), identifying parameters useful in evaluating viability at the population- and ESU-levels and giving guidelines for assessing population and ESU status (McElhany et al. 2000). The parameters identified in the VSP document for evaluating population viability are abundance, productivity, spatial structure, and diversity. For evaluating ESU-level viability, important considerations include the risk of catastrophic events, long-term demographic processes, and long-term evolutionary processes.

The TRTs' shared understanding of viability is apparent in the narrative portions of each TRTs viability criteria document (Boughton et al. 2007; Cooney et al. 2007; Lindley et al. 2007; McElhany et al. 2006; Ruckelshaus et al. 2002; Sands et al. 2007; Spence et al. 2007; Wainwright et al. 2007; Williams et al. 2007). However, McElhany et al. (2000) is intentionally general. The authors state that they developed the viability guidelines so that the guidelines can be applied across the wide spectrum of life-history diversity, habitat conditions, and metapopulation structures represented by Pacific salmon (McElhany et al. 2000).

Translating VSP Guidelines into Viability Criteria

For a variety of reasons, including the generality of the guidelines in McElhany et al. (2000), viability criteria vary among TRTs. These differences are apparent by simply looking at a flow chart for each TRT's viability criteria (Figure 2). For example, to assess viability, the Oregon Coast (OC) TRT's criteria evaluate many different parameters at multiples levels of organization (population, major population group[3]

[3] A group of populations that share similar environments, life-history characteristics, and geographic proximity within an ESU (McElhany et al. 2006). (An ESU is a distinct segment (population or groups of

[MPG]), and ESU). In contrast, the Puget Sound TRT's criteria focus on very few parameters to accomplish the same assessment. Variation in the viability criteria among domains can be attributed to four main factors:

1) Biological and ecological differences
2) Variation in data availability
3) Composition of the TRT
4) Interaction with different policy groups

Given the large area included in the recovery domains, biological and ecological differences among the domains are expected. The factors that form the basis of these differences are several fold: listed species in the domain, location of listed ESUs in relation to the species' ranges, and spatial configuration of the listed ESUs. Which species are present in a domain and the number of species present likely influenced the conceptual underpinnings and analytical techniques chosen by the TRT. It is reasonable to expect that viability criteria for species with relatively complex life histories (i.e., steelhead) might differ from those of species with less variable life histories (e.g., coho salmon). Domains with just one species (OC, Southern Oregon/Northern California Coast (SONCC), and South-Central/Southern California Coast (SCSCC)) could tailor viability criteria to the species of concern. Other domains were forced to either develop more generic models that could capture the biology of multiple species or focus on one or two species within the domain. In contrast, the Puget Sound (PS) TRT developed viability criteria for each of the listed species in their domain separately, based on specific policy direction within their domain.

The location of listed ESUs in relation to the species' ranges also varies among domains. Compared to ESUs at the periphery of their geographic distribution, ESUs that are towards the center of their geographic distribution are likely to have different

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populations) of a Pacific salmon species that is substantially reproductively isolated from conspecific segments and represents an important component of the evolutionary legacy of the species. See Waples (1991).) TRTs used different names for MPGs (diversity groups, diversity strata, strata, geographic regions, biogeographic groups), and there are some conceptual differences in how MPGs are defined.

mechanisms that regulate them, such as ocean and freshwater conditions or limits of physiological tolerance. As viability criteria are influenced by the mechanisms that regulate ESUs, the location of the ESU compared to the species' range likely causes difference among the TRTs' products.

The final major consideration in terms of the biological and ecological differences among the domains concerns the spatial configurations of the ESUs. Some domains, such as the SCSCC and the North-Central California Coast (NCCC), are dominated by a series of small to moderate-sized rivers entering directly into the ocean. Other domains, such as the Central Valley (CV) and Interior Columbia (IC), are dominated by highly-dendritic, inland systems, where all populations share common migratory pathways to the ocean. It is reasonable to expect that the primary drivers of extinction risk (e.g., disturbance regimes, genetic processes) vary across these situations. Hence, the viability criteria themselves and the models used to predict viability should likewise be expected to vary in order to reflect these differences.

Variation in data availability is the second main factor to which differences among the viability criteria can be attributed. For example, due to the lack of abundance time series for most California salmonid stocks, the Salmon Recovery Science Review Panel recommended that the California TRTs model their recovery criteria after the less data-intensive IUCN criteria (IUCN 2001) in addition to McElhany et al. (2000)'s viable salmonid population guidelines (Salmon Recovery Science Review Panel 2002). Heeding this suggestion, the California TRTs' criteria are all based on a modified form of the IUCN criteria that rely less heavily on quantitative models to assess abundance and productivity (Allendorf et al. 1997). Not only are there far fewer time series of abundance in California, but there is very little information on a variety of parameters needed for developing more complicated population viability models. For example, we know very little about marine survival and fish-habitat relationships for California salmonid populations, as most of the studies on these topics were conducted outside of California.

The third factor to which difference among the viability criteria can be attributed is the composition of the TRTs and the timing of their work. The value of bringing together scientific panels for a process such as this lies in the different expertise that each team member brings from different disciplines. Further, different TRT members may have different perspectives on which processes (and hence criteria) may be most important for assessing viability, how much confidence they place in various types of models, how precautionary viability criteria should be, and any number of other factors that ultimately were considered in the final products.

The fourth factor affecting differences in the viability criteria is the nature of interactions between TRTs and different policy groups. In the Northwest region, the TRTs worked with state, tribal, and local government agencies and other organizations that led the recovery planning effort. The number and nature of the groups that the Northwest TRTs worked with varied widely. For example, the PS TRT worked solely with group called "Shared Strategy for Puget Sound", which included NMFS, the U.S. Fish and Wildlife Service, Governor's Office, Puget Sound treaty tribes, state natural resources agencies, local governments, and key non-government organizations. The Shared Strategy strongly guided the PS TRT, giving the TRT tight deadlines for products and direction on sequencing work on the 3 ESUs within their domain. The WLC and IC TRTs worked with multiple groups including the Northwest Power and Conservation Council and several local and regional planning groups. In contrast, in the Southwest, NMFS led the effort to develop recovery plans for ESA-listed salmon and steelhead. Thus, in the Southwest region, the TRTs did not interact with the government or community groups charged with developing recovery policy. Because of their interactions with different policy groups, the TRTs had different deadlines for producing their viability criteria. These differing deadlines affected both the amount of time the TRTs had to develop their criteria and their ability to build on the work of other TRTs (Table 1). For example, the PS TRT was given 1 year to develop the viability criteria for Puget Sound Chinook salmon and, as they were the first TRT to complete a viability criteria document for a Pacific salmonid, created their criteria *de novo*. In contrast, the

Willamette/Lower Columbia (WLC) TRT took six years to work on their viability criteria and was able to incorporate ideas from other TRTs.

In the sections below, we compare how the TRTs proposed to assess viability and do so in the VSP framework of McElhany et al. (2000). A detailed summary of the viability criteria documents is contained in the Viability Criteria Comparison Table.

Population-level criteria

<u>Population Abundance and Productivity</u>

Abundance

The TRTs address population abundance in two ways: 1) criteria that outline thresholds in abundance or density or 2) criteria that evaluate whether abundance is adequate given the population's productivity (PVA models) (Table 2). (In this essay, PVA models are referred to as "models"; all other types of criteria are termed "metrics".) Both models and metrics use time series of abundance as the basis for analysis, but models typically need longer time series. For example, metrics use time series data to evaluate the status of a population against predefined thresholds. Thresholds are defined by literature review and expert opinion, not by the characteristics of the time series itself. In contrast, models use time series data to both define what a viable state is and assess whether the population meets that state. All of the TRTs used both models and metrics in their abundance criteria, but the California TRTs eliminate models for populations lacking sufficient data. The two metrics used to assess abundance are as follows: minimum population size (WLC, IC, OC, CV, SONCC, NCCC, and SCSCC) and population density (OC, SONCC, NCCC, and SCSCC). Minimum population size thresholds for these metrics are based, in part, on the number of fish needed to avoid the deleterious genetic and demographic effects of small population sizes. Some TRTs vary minimum population size depending on both the amount of habitat available to the population and the species (WLC, IC). Others vary minimum population size thresholds based on the effective number of spawners (CV, NCCC, SONCC). Density thresholds are typically based on the density of individuals needed to avoid depensation. The distinction between how models and metrics are used to assess abundance can be blurred; viability criteria developed by the Puget Sound TRT use population-specific, model-based criteria to set population-specific goals for minimum population size threshold metrics.

Productivity

Productivity can also be assessed using either metrics or PVA models. The WLC, IC, and SCSCC TRTs used only PVA models to evaluate productivity (Table 2). The PS, OC, CV, SONCC, and NCCC used both models and metrics from abundance time series to evaluate productivity (Table 2). As with their evaluation of abundance, the California TRTs eliminate models for populations with inadequate data. In terms metrics, the PS Chinook TRT evaluates whether the population growth rate from a Dennis-Holmes random-walk-with-drift model is positive, the OC TRT evaluates the mean recruits/spawner during periods of low abundance, and the California TRTs (excepting SCSCC) evaluate the slope of abundance time series over at least the past 2-4 generations (more data are used if available, depending on how the results of analyses on the entire dataset compare with analyses on the most recent generations). The CV, NCCC, and SONCC TRTs also evaluate the impact of prior catastrophes on productivity by screening abundance time series for extreme population decline events. For all of these metrics, data on the population is evaluated against predefined thresholds to generate the extinction risk status of the population for that specific metric.

The different TRTs use quantitative models with different structure and parameter types to assess abundance and productivity, except for the use of the Kalman-filtered, density-independent random-walk-with-drift model by both the SCSCC and CV TRTs. Estimates of productivity vary with model structure and the types of parameters built into the model. Viability forecasts vary for additional reasons such as the assignment of quasi-extinction thresholds. Addressing the specific details of the quantitative models is beyond the scope of this review, but some general information on the model basics is informative and is given here and in Table 3. More thorough descriptions of the abundance and productivity models and metrics used by the TRTs and a comparison of their performance will be included in future work by SB. Density-dependent, age-structured abundance/productivity models are used by the OC, WLC, and IC TRTs. A density-independent model with no age structure is used by the CV and SCSCC TRTs, and the SCSCC TRT also uses a density-dependent model with no age structure. Both density-dependent and independent models are used by the PS TRT for Puget Sound Chinook salmon and Hood Canal Summer Chum salmon. In addition, results from a habitat-explicit model (EDT) developed by an outside group (state and tribal scientists) are combined, using decision rules, with the TRT analyses to develop viability criteria for Puget Sound Chinook. Due to the lack of data to develop and validate models with, the SONCC and NCCC TRTs do not specify a quantitative model to set abundance and productivity criteria.

Influence of environmental conditions on abundance and productivity

Conservation biologists generally recognize that abundance and productivity should be high enough to enable populations to persist at viable levels through poor environmental conditions and to be resilient to environmental perturbations, and this principal was incorporated into McElhany et al. (2000)'s guidelines for viable salmonid populations. The most common way the TRTs incorporate environmental condition information into abundance and productivity assessments is by including ocean condition, as calculated by survival of hatchery fish in the marine realm, as a parameter in viability models. A time series of ocean condition is incorporated into the IC TRT model, one of the PS (chum) TRT's models, and three of the OC TRT's models. The SCSCC TRT stipulates that the population size criterion should be met during poor ocean conditions and provides an example indicating how the impact of changing ocean conditions could be incorporated into their model-based criteria. In this example, they change the parameter value for ocean survival from 1% survival to 0.2% survival and evaluate how this change affects extinction risk estimates. The CV, PS (Chinook), and WLC TRTs do not directly incorporate environmental conditions into their criteria. Instead, they assume that environmental conditions such as ocean regime shifts will be incorporated into abundance time series and emphasize that longer time series will more accurately incorporate the range of conditions that each population experiences. The NCCC and SONCC TRTs specify that evaluation of several of their metrics (e.g., population size, trend) should be done in the context of information on marine survival.

For example, a population that exceeds minimum size thresholds for 3-4 generations during a period of unusually high marine survival may still be classified as at risk of extinction. Likewise, a population experiencing a minor negative trend might still be considered viable with knowledge that the short-term trend was driven by poor ocean conditions.

Population Spatial Structure

All TRTs include at least one metric to assess populations' spatial distribution. These spatial-structure metrics aim to, among other considerations, decrease the probability that the entire population will be affected by a single disturbance and increase the chance that spawning aggregations are close enough to rescue each other should a catastrophe strike. When considering the spatial structure of populations, the TRTs assume that, unless otherwise specified, the occupied habitat included in their analyses is of good enough quality to permit adequate productivity. While the principles behind the spatial structure metrics are similar among TRTs, the metrics they developed are different. TRTs address spatial structure in seven ways: number of spawning areas in a population or population density (fish/unit habitat), arrangement of spawning areas, connectivity among spawning areas, habitat quality, range of population, ecoregions occupied by spawning aggregations, and the risk due to catastrophes (Table 2). The number of metrics each TRT uses to assess spatial structure varies: the IC TRT evaluates spatial structure with five metrics while the CV TRTs used one metric.

The number of spawning areas in a population or population density is addressed by most TRTs (number of spawning areas: IC, OC, PS (Chum); population density: NCCC, SONCC, SCSCC). While these two metrics are distinctly different, they address the same goal: ensuring that the historical spawning distribution is reasonably represented. The IC and PS TRTs include metrics for the arrangement of spawning aggregations and the IC and PS TRTs include metrics for the connectivity among spawning aggregations. The WLC and OC TRTs evaluate the current quality of occupied habitat. The IC, PS (Chum), and WLC TRTs assess the range of the population; the IC and PS (Chum) TRTs extend this metric further by evaluating the change in the ecoregions between historical and current fish distributions. Although these last two metrics are explicitly included by just three TRTs, they are implicitly incorporated into other spatial structure metrics by some TRTs. For example, it is assumed that populations meeting the NCCC and SONCC density requirements would *de facto* inhabit a significant proportion of their historical distribution and be distributed among ecoregions.

The risk of catastrophes is evaluated at the population and subpopulation levels. The WLC, CV, PS (Chinook), and SSCCC TRTs evaluate population-level risk due to a suite of catastrophes. Most of these TRTs use this risk-of-catastrophe information to develop arrangements of populations that reduce the susceptibility of an entire MPG or ESU to catastrophic risk (Good et al. 2008; Lindley et al. 2007; McElhany et al. 2006; Ruckelshaus et al. 2004). The WLC TRT incorporates the composite risk-of-catastrophe information into population viability evaluation. The OC and PS (Chum) TRTs focus on the sub-population level, requiring that spawner aggregations be well-distributed in order to spread the risk of catastrophe.

Population Diversity

The TRTs use three types of approaches to evaluate population-level diversity: effective population size, impact of anthropogenic activities, and phenotypic and genotypic diversity (Table 2). As with spatial structure criteria, the number and type of metrics included within these categories varies widely among TRTs, resulting in viability criteria that seem very different at first glance. Effective population size is measured by an estimate of the effective spawners (generated using standard ratios between total and effective spawners; WLC, CV, NCCC, SONCC), the total number of fish that return to spawn (OC, CV, SCSCC, NCCC, SONCC), and/or spawner density (SCSCC, SONCC, NCCC, PS (Chum)). The California TRTs' density metric assesses whether the number of fish per unit usable area is high enough that the population is likely spread throughout the landscape, occupying a broad range of environmental conditions. Fish exposed to different environmental condition are more likely to have greater phenotypic and genotypic diversity. The PS TRT's (Chum) density metric calculates Shannon and

Simpson's diversity indices using the number of spawning aggregations in a population and the abundance of spawners per aggregation, with the assumption that the higher the index score, the more distributed and diverse the population is.

Most TRTs incorporate the impact of anthropogenic activities via assessing the proportion of hatchery-origin to wild-origin fish spawning in the wild (OC, IC, WLC, CV, NCCC, SONCC). The OC and IC TRTs use a second metric to evaluate the impact of hatchery fish on wild populations – the amount of introgression of exotic genes into the wild population. In addition to assessing the impact of anthropogenic activities via evaluation of hatchery impacts, the WLC and IC TRTs include a metric for human-driven selection at the population level. The WLC TRT evaluates the impact of harvest activities, while the IC TRT evaluates the cumulative selective impact of all anthropogenic activities, which could range from hydropower generation to forestry.

The third type of approach used to assess diversity is describing phenotypic and genotypic diversity, through either direct or indirect measures. The SCSCC and PS (Chinook) TRTs include direct measures of phenotypic diversity by indicating that a representation of phenotypes/life-history types should be present in a population for it to be viable, and the PS (Chinook) TRT further recommends that phenotypic variation should be similar to historical levels. Likewise, the WLC TRT focuses only on phenotypic diversity and emphasizes the types of changes that are most important (loss of trait, decline in variability of trait, and shift in mean of trait). The TRT specifies two traits that should be assessed (stray rate and life-history strategy) and suggests that trait analysis be done on any other relevant data sets that are available. The IC TRT calls for measurement of variation in both phenotypic and genotypic diversity. Finally, using the rationale that a population should have a range of genotypes and phenotypes to cope with the range of environmental conditions, the environmental characteristics of occupied habitat is an indirect measure of diversity included by the WLC and PS (Chum) TRTs.

ESU-level Criteria

McElhany et al. (2000)'s synthesis of the conservation biology literature indicates that the three considerations important for ESU viability are: risk of catastrophic events, long-term demographic processes, and long-term evolutionary processes. However, McElhany et al. (2000) do not state how population-level data should be used to inform these ESU-level considerations. Most TRTs use population-level analyses on abundance and productivity, spatial structure, and diversity to address MPG viability, and MPG-level analyses on evolutionary and demographic processes and the impact of catastrophes to address ESU viability. Which metrics were chosen by the TRTs to evaluate MPG viability demonstrates the processes the TRTs thought are most important for ESU viability in their domain (Table 2).

Although viability criteria vary at the MPG level, the same metric is used by all TRTs to define ESU viability: for an ESU to be viable, all MPGs in the ESU should be viable. (For the PS and IC ESUs with a small number of populations (1-4) and just one MPG, ESU viability depends on all populations being viable. The CV winter-run Chinook ESU historically had just 4 populations. Because all of these historical populations are extinct and none of the historical spawning grounds are currently accessible, the CV TRT does not require that all 4 populations be viable.) This MPG-redundancy criterion makes sense particularly for spatial structure and diversity analyses given the definition of an MPG: a group of populations that are more similar to other populations in the ESU on the basis of genetics, geography, and ecology. The TRTs thus assume that if all MPGs are viable, the ESU will be viable in terms of spatial structure and diversity. The OC TRT was the only TRT to include other ESU-level metrics. Twelve of fourteen of the OC TRT's diversity metrics are evaluated at the ESU level. Most of these metrics can be grouped into the categories phenotypic/habitat diversity and genetic diversity, and include the following metrics: age and size at maturity, smolt age, juvenile run timing, adult run timing, spawning timing, habitat productivity, habitat accessibility, habitat diversity, effects of human-selection, effects of migration, genetic structure, and status of dependent populations.

ESU Long-term Demographic and Evolutionary Processes

As many of the metrics used to evaluate long-term demographic processes also apply to long-term evolutionary processes, the two parameters are treated together here. At the MPG-level, long-term demographic and evolutionary processes are evaluated with four types of metrics: population viability, diversity present within the MPG, abundance and productivity, and population connectivity (Table 2). For most TRTs, a number of viable populations are needed to achieve MPG viability (PS Chinook, IC, CV, SONCC, NCCC, SCSCC). Two TRTs (WLC and OC) instead calculate the average viability of all populations in the MPG. The IC TRT has one additional population-level requirement for MPG viability: to be viable, each MPG should contain at least one highly viable population.

Most of the TRTs include separate measures of diversity at the MPG level. The WLC and OC TRTs use population-level information to inform MPG diversity – the WLC TRT scores MPG viability using the average extinction risk of all populations and the OC TRT evaluates MPG diversity using data on population sustainability and persistence. The SCSCC TRT evaluates diversity at the MPG level by assessing the representation and redundancy of all diversity groups. Similarly, MPG viability for the PS Chinook TRT depends on having one population from each major genetic and life-history group be viable, the IC TRT depends on having all major life-history groups be represented by viable populations, the CV TRT depends on having at least two populations be viable in terms of diversity, and the NCCC TRT depends on having viable populations contain all of the extant phenotypic diversity present in the MPG. The PS Hood Canal Summer Chum viability criteria does not define MPGs because the ESU contains only two historical populations, both of which must be viable for ESU viability.

MPG-level abundance and productivity is evaluated by four TRTs with the following metrics: IC—MPG productivity at or above replacement and all population sizes present; SONCC/NCCC—aggregate abundance of viable populations; and OC—MPG persistence. Finally, connectivity among populations is included by the OC TRT (effect of migration) and the SONCC and NCCC TRTs (viable populations arranged to preserve connectivity and immigration from viable to non-viable populations).

<u>ESU Risk of Catastrophic Events</u>

The impact of catastrophes can be addressed at the population level, ESU level, or both levels. The population-level metrics discussed above focus on the impact of past catastrophes on population productivity, the risk to a population from a suite of catastrophes, and the spatial arrangement of spawning aggregations. To increase ESU viability in the face of catastrophes, ESUs should contain multiple populations (redundancy), some populations should exceed viability guidelines, some populations should be geographically widespread, populations should not all share common catastrophic risks, and populations should display diverse life histories and phenotypes (McElhany et al. 2000). By making ESU viability dependent on the viability of all MPGs, all TRTs incorporated redundancy as a way to mitigate the impact of catastrophes at the ESU level. Additional consideration of catastrophes at the MPG and ESU levels varies among TRTs (Table 2). The differences in these additional considerations relate to how specific TRTs are about the likely types of catastrophes within a particular ESU and whether the catastrophes are likely to affect a single population or multiple populations.

At the MPG level, catastrophes are analyzed in terms of redundancy, abundance, and spatial structure. To reduce the risk due to catastrophe at the MPG level, all TRTs state that viable MPGs should have multiple viable populations (redundancy). This rule also implicitly incorporates the role that diversity plays in mitigating the risk due to catastrophes at the MPG level. Additional abundance-related catastrophe metrics at the MPG level are included by the IC, NCCC, and SONCC TRTs. MPG viability for the IC TRT depends on having at least one highly viable population per MPG and for the NCCC and SONCC TRTs depends on non-viable populations exhibiting occupancy patterns consistent with sufficient immigration from viable populations. Both of these metrics are included to enhance the probability that demographic exchange can rescue a MPG post-catastrophe. In terms of spatial structure, the WLC, PS Chinook, SCSCC, and CV TRTs use detailed population-level information on catastrophe risk to determine distribution patterns with low probability that all viable populations would be impacted by the same catastrophic event. Instead of focusing on the distance between populations needed to avoid impact by the same catastrophic event, the SONCC and NCCC TRTs focus on how close populations need to be to allow immigration to populations impacted by catastrophes.

Summary of all metrics

A number of patterns regarding the similarities and differences of the TRTs' viability criteria have emerged from this summary and are apparent by studying Table 2. The metrics included by the SONCC and NCCC TRTs are nearly identical. No other sets of viability criteria are as similar to each other, including the criteria from the two TRTs with only listed coho (OC and SONCC). The most uniform set of metrics are for population-level abundance. All TRTs include a minimum population size metric and half of the TRTs include a density metric. All TRTs call for assessment of population productivity using a PVA, though, due to a lack of available data with which a tailored model could be developed for the domain, two TRTs (NCCC and SONCC) do not specify a PVA model. Most TRTs use metrics to assess population productivity, with only three TRTs assessing the impact of past catastrophic events on productivity.

The most divergence among the viability criteria occurs in the population-level spatial structure metrics. Most TRTs include a metric to address catastrophes using data on the spatial distribution of populations or spawning aggregations. Two thirds of the TRTs have a metric assessing the number of spawning areas or density of the population. The Northwest TRTs measure spatial structure using five additional metrics. Population-level diversity is evaluated by most TRTs with metrics assessing anthropogenic effects and effective population size. Many TRTs also include a metric on genotypic/phenotypic diversity. The impact of catastrophes at the MPG-level is assessed mostly by metrics on redundancy and spatial structure, though three of the TRTs also include a metric on abundance. All TRTs assess demographic and evolutionary processes at the MPG level with metrics on population viability and diversity, and half of the TRTs also include

MPG-level metrics on abundance and productivity and connectivity. All TRTs have the same metric for ESU viability.

Combining metrics into one population-, MPG- or ESU-level score

The outcome of viability criteria depends not only on the metrics that are used to assess viability, but the way in which these metrics are combined or "rolled-up" into a single score for each population, MPG, or ESU. The TRTs combine metrics using six calculations: average, weighted average, median, highest risk, expert opinion, and the logical operator "and" (which evaluates to "true" if all of its antecedents are true or to "false" if any of the antecedents are false). Most TRTs use a number of these calculation types in their viability criteria. The techniques for rolling-up metrics are precautionary to different degrees, with the "highest risk" and "logical operator 'and'" calculations being the most precautionary methods. It should be noted, however, that use of precautionary methods for rolling-up does not equate directly with precautionary viability criteria; viability criteria are influenced by both roll-up techniques and the risk associated with the thresholds set for models and metrics. For example, a TRT using the precautionary "highest risk" operator could set their metric thresholds lower relative to other TRTs.

In addition to the metric scores themselves, some TRTs incorporate uncertainty around each metric in their roll-up techniques. Standard deviation and confidence intervals around the output of the abundance and productivity models are used by all TRTs. Three TRTs incorporate uncertainty into their metrics for spatial structure and diversity. The WLC TRT estimates the uncertainty in their metric scores for spatial structure and diversity by asking a panel of experts to develop a probability distribution for each metric. Similarly, the IC TRT categorizes the certainty of each metric score as high, medium or low, and does so by considering the following: 1) the completeness of the spatial and temporal coverage within a year, 2) the length of the time series for the metric, 3) the precision and accuracy of the metric, 4) information for a specific metric from a population deemed to have similar characteristics to the focal population, 5) if they used information from surrogate metrics, and 6) if they had no data to address the metric. If the data certainty for an IC TRT metric is low, its risk rating is increased by one level and if no data are available, the lowest risk rating an IC TRT metric can get is "moderate". Finally, the OC TRT uses a fuzzy logic framework for all of their metrics. In this framework, each metric is assigned two scores: one for the truth of the statement and the second for the certainty of this first answer. How certainty is evaluated depends on the metric in question. In order to handle the large number of metrics they use and their fuzzy logic framework, the OC TRT uses a decision support system to automate the roll-up process.

Conclusions

Although the TRTs worked independently to develop viability criteria for the ESA-listed salmon ESUs in their domain, their viability criteria are fundamentally very similar. Each TRT followed the guidelines outlined by McElhany et al. (2000), and these guidelines are broad enough that the TRTs could tailor their criteria to the status and biology of the listed-fish in their domain and available data. The major differences among the TRTs' viability criteria concern how many metrics the TRTs developed (Figure 2, Table 2) and for which population structure level they developed metrics (population, MPG, or ESU). These differences in metric specificity, the population structure level at which metrics were developed, and the incorporation of uncertainty in metric roll-up are related to the degree to which regional biology, data availability, and the experience and opinions of the TRT members affected the viability criteria. In addition, the amount of time TRTs had to develop criteria, and the order in which they conducted their analyses (and thus could learn from previous TRT efforts) affected the complexity and nature of the approaches. Quantitative analyses that compare the performance of the viability criteria's models and metrics are currently underway.

We hope that policy and management specialists will use the descriptive analyses presented here and future quantitative analyses to further evaluate the impact of having multiple teams of scientists develop the viability criteria for ESA-listed Pacific salmon and steelhead. Recovery plans for listed salmon and steelhead explicitly state that viability criteria will be adaptively managed as part of the implementation process. We believe that incorporation of the lessons learned from this project will benefit the next steps of management for ESA-listed Pacific salmon and steelhead (status assessments, evaluating status against delisting criteria, modification of viability criteria) and is in line with the goals stated for recovery plans.

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List of acronyms:

CV: California Central Valley

ESA: Endangered Species Act

ESU: Evolutionarily-Significant Unit

IC: Interior Columbia

IUCN: International Union for the Conservation of Nature

OC: Oregon Coast

NCCC: North/Central California Coast

NMFS: National Marine Fisheries Service

OC: Oregon Coast

PS: Puget Sound

SCSCC: South-Central/Southern California Coast

SONCC: Southern Oregon/Northern California Coast

TRT: Technical Recovery Team

VSP: Viable Salmonid Population

WLC: Willamette/Lower Columbia

Table 1. Initiation date of each TRT, release date for the first draft of its viability criteria, and the publication date of the final draft of its viability criteria.

Domain	**First Meeting**	**Draft Viability Criteria Completed**	**Final Viability Criteria Completed**
Puget Sound (Chinook)	April 2000	–	April 2002
Puget Sound (Chum)	April 2000	–	February 2007
Interior Columbia	October 2001	July 2005	March 2007
Willamette/Lower Columbia	May 2000	March 2003	April 2006
Oregon Coast	November 2002	August 2007	June 2008
Southern Oregon/Northern California Coast	October 2001	July 2007	In final prep.
North-Central California Coast	October 2001	June 2007	April 2008
Central Valley	March 2003	February 2006	February 2007
South-Central/Southern California Coast	November 2003	March 2007	July 2007

Table 2. Population, MPG, and ESU level metrics used by each TRT to assess viability. A "Yes" indicates that a TRT includes a metric in that category and a "No" indicates that no metric was used by the TRT for that category. "NA" is given for PS Hood Canal Summer Chum MPG- and ESU-level metrics because no MPGs were defined by the TRT and the MPG- and ESU-level metric summaries used here do not apply. See text for descriptions of how each metric was used.

	Population Level															**MPG Level**							**ESU Level**	
	Abundance		**Productivity**			**Spatial Structure**							**Diversity**			**Catastrophe**			**Dem/Evo Processes**					
TRT	Minimum population size	Density	PVA model	Other metric	Impact of past catastrophic event	# spawning areas or density	Arrangement of spawning areas	Connectivity	Habitat quality	Range	Ecoregions inhabited	Impact of catastrophes	Effective population size	Anthropogenic effects	Genotypic/phenotypic diversity	Redundancy	Abundance	Spatial structure	Population viability	Diversity	Abundance and productivity	Population connectivity	All MPGs viable	Diversity
PS Chin.	Yes	No	Yes	Yes	No	No	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No
PS Chum	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	NA	NA	NA	NA	NA	NA	NA	NA	NA
WLC	Yes	No -	Yes	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No -	Yes	Yes	Yes	No	No -	Yes	No
OC	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
IC	Yes	No	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
SONCC	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No
NCCC	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
CV	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes	No
SCSCC	Yes	Yes	Yes	No	No	Yes	No	No	No	No	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No

Table 3. Summary of abundance and productivity models developed by the TRTs. Multiple columns below a domain name indicate that the TRT uses multiple abundance and productivity models for their viability evaluation.

	Domain										
	Puget Sound		Willamette/ L. Columbia	Interior Columbia	Oregon Coast				Central Valley	S/S.-Central Cali Coast	
Dataset used for recruit function	Escapement + Catch	Escapement + Catch	Escapement + Catch or Escapement	Escapement	Escapement+ Catch	Escapement+ Catch	Escapement	Escapement	Escapement	Escapement	Escapement
Portion of dataset used	Full, period when abund. is stable and high	Full	Full	Last 20yrs	Full	Full	Full	None	Full	Full	Full
Model for recruit. function	Slope adjusted RWWD[1]	Hockey stick, Beverton-Holt or Ricker	Mean R/S	Modified mean R/S with model average for σ and autocorr.	Hockey Stick	Modified Ricker	Beverton-Holt	Complex egg-to-parr and parr-to-smolt functions	Kalman-filtered RWWD	Kalman-filtered RWWD	Density-depend., Kalman-filtered RWWD
Model for projection	RWWD	Hockey stick, Beverton-Holt or Ricker	Hockey Stick	Hockey Stick	Hockey Stick	Modified Ricker	Beverton-Holt	Complex egg-to-parr and parr-to-smolt functions	RWWD	RWWD	RWWD
QET	63/yr	63/yr	Coho/Chum: 100, 200, 300/gen[2] Chinook: 50, 150, 250/gen Steelhead: 50, 100, 200/gen	50/yr	1 or 50/gen	0/gen, 50/gen or 1fish/mile	0 or 50/gen	0/gen, 50/gen or 1fish/mile	None	1 or 10/yr	1 or 10/yr
Depensation function	QET	QET + other	QET	QET	QET	QET + other	QET + other	QET + other	QET	QET	QET
Incorp. ocean survival data	No	Yes	No	Yes	No	Yes	Yes	Yes	No	No	No
Rel. prod. of hatchery fish	0.7	Equal	Equal	Equal	Equal	Equal	Equal	Not considered	Equal	Equal	Equal

1. RWWD stands for Random-walk-with-drift

2. “gen” stands for `generation

Figure 1. Recovery domains for ESA listed Pacific salmon and steelhead.

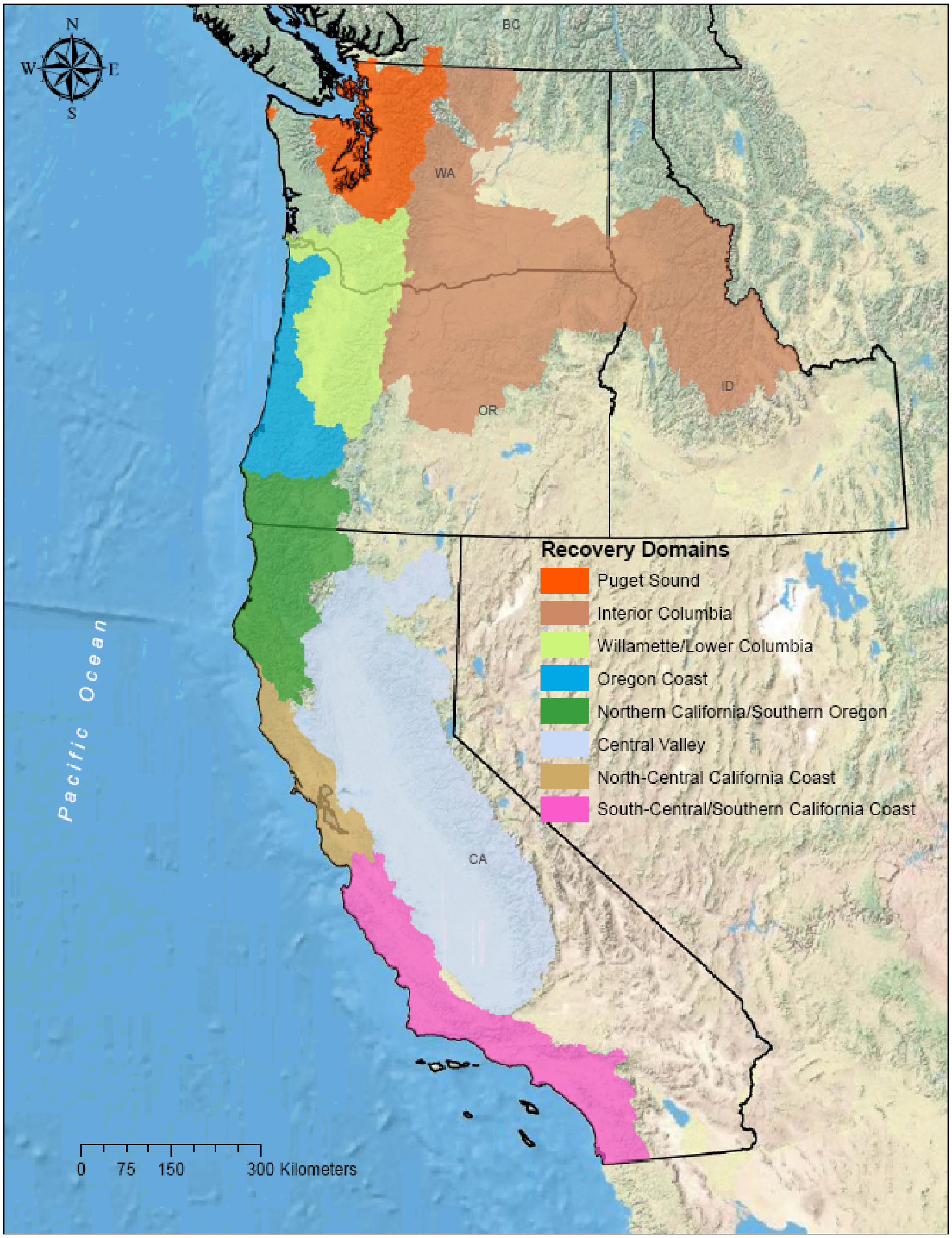
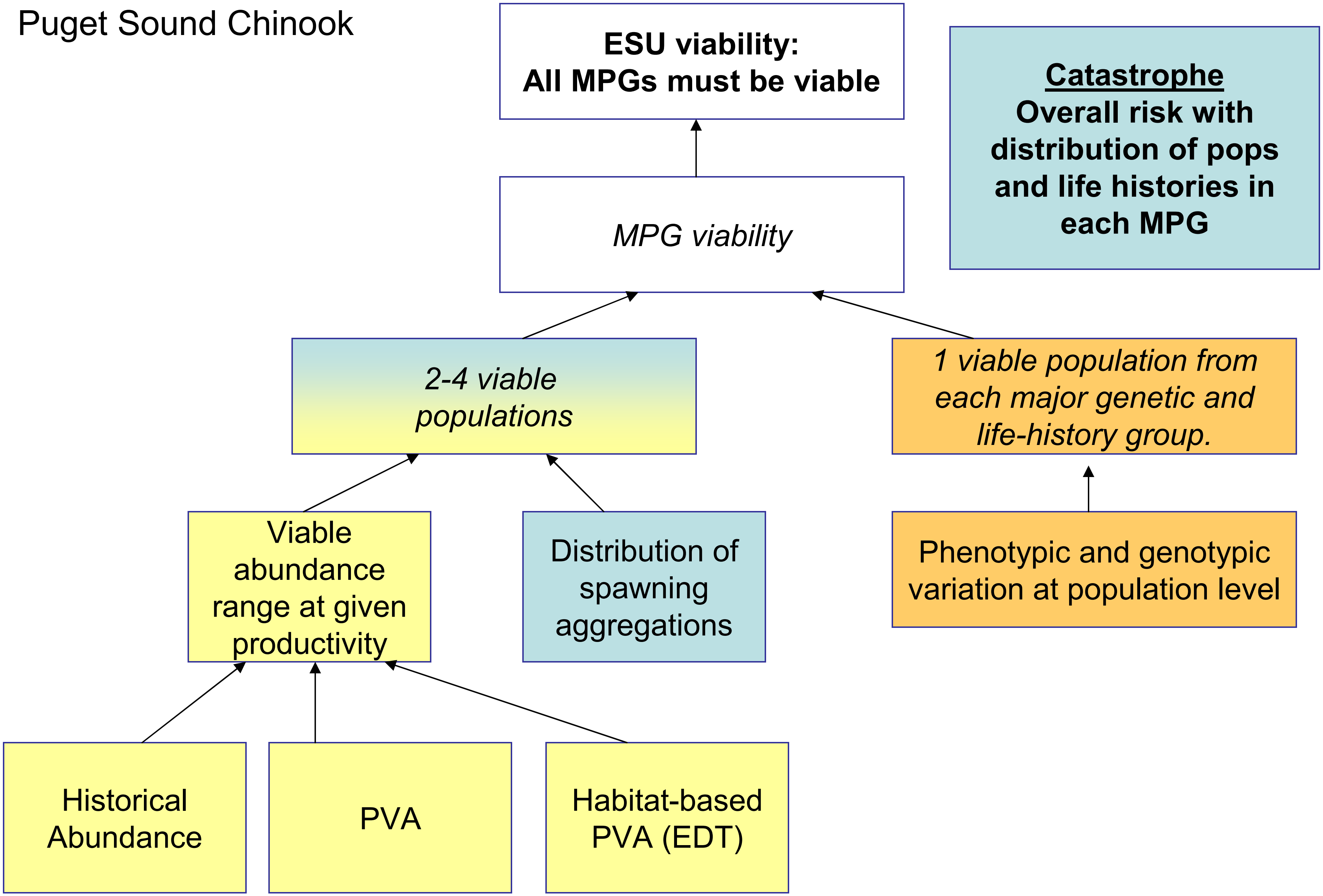
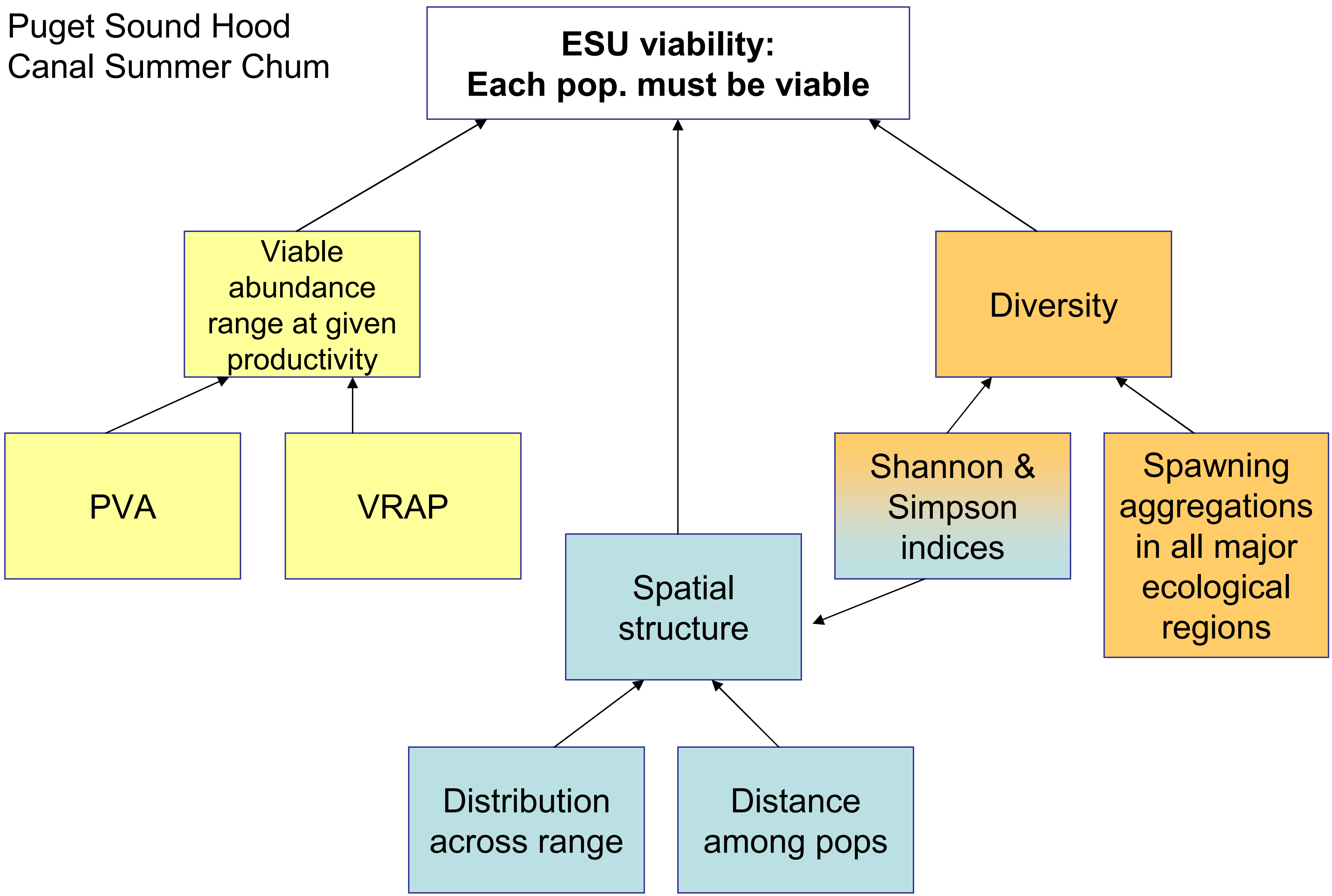
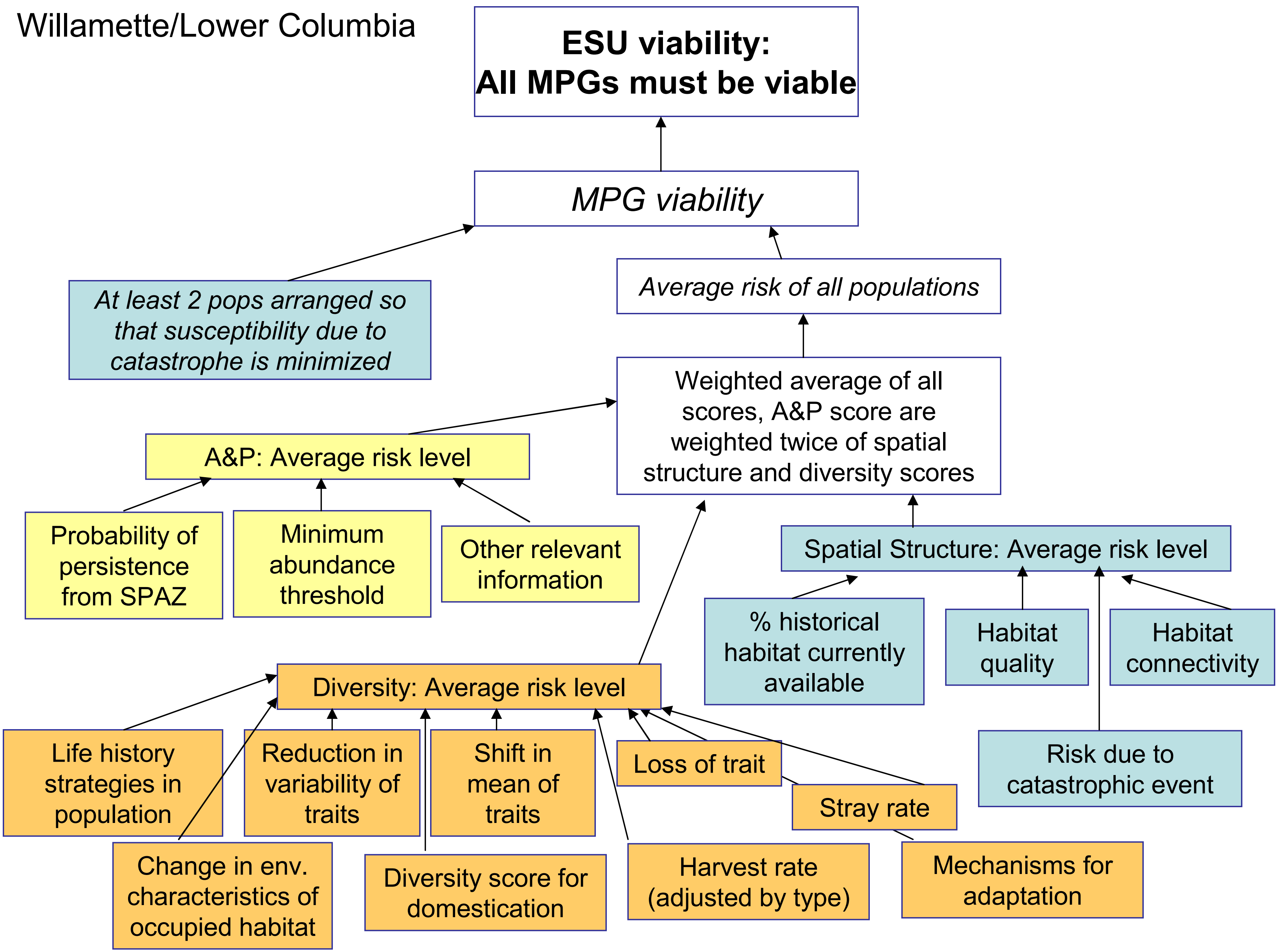


Figure 2. Flow chart of the metrics included in each TRTs viability criteria. Box shading indicates for what type of analysis each metric is used: yellow for abundance and productivity, blue for spatial structure, and orange for diversity. The metrics that fall into multiple categories are shaded with two or three colors. Font type is used to indicate the level at which each metric is addressed: plain text for population level, italics for MPG level, and bold for ESU level.

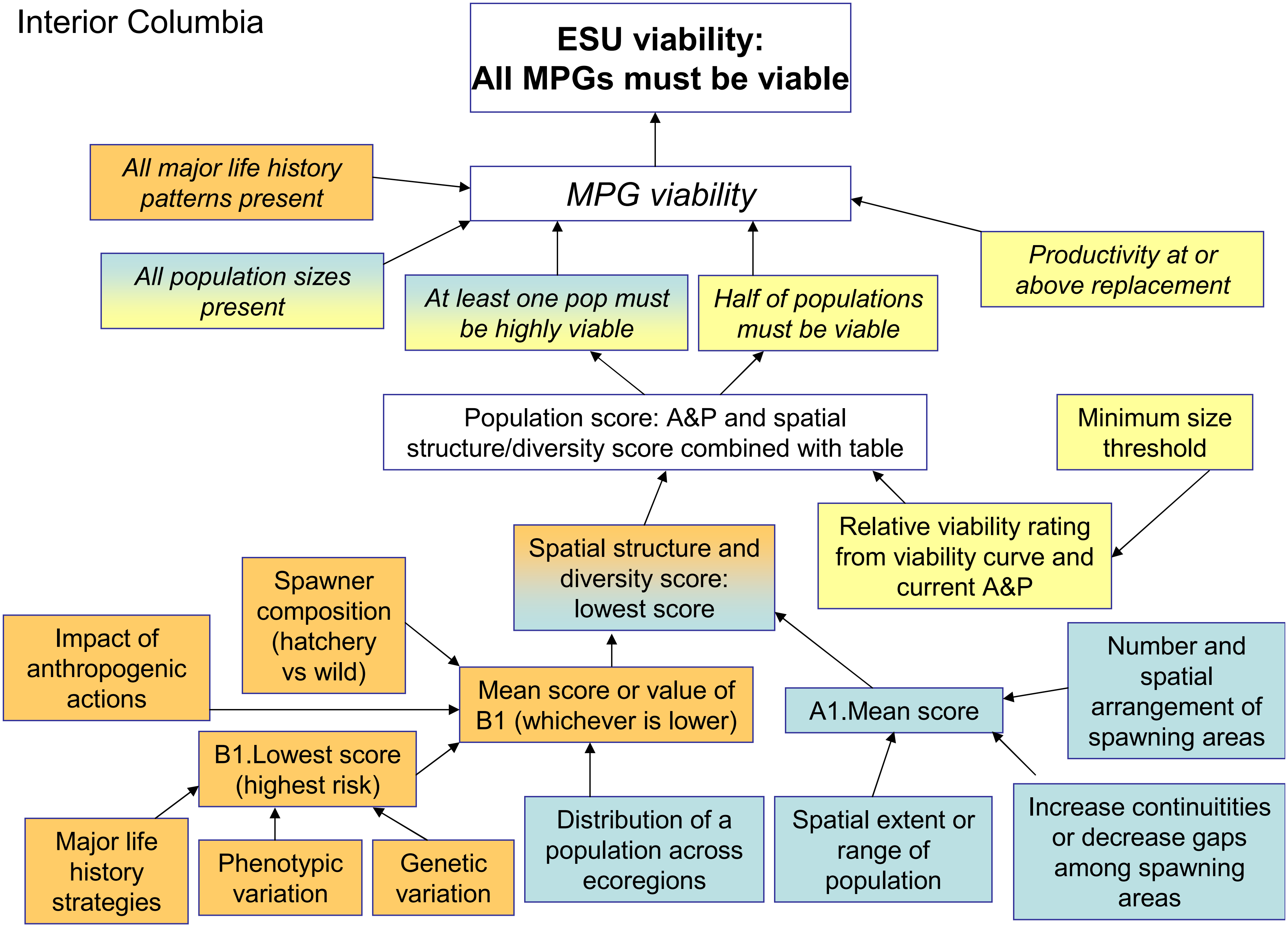
Puget Sound Chinook

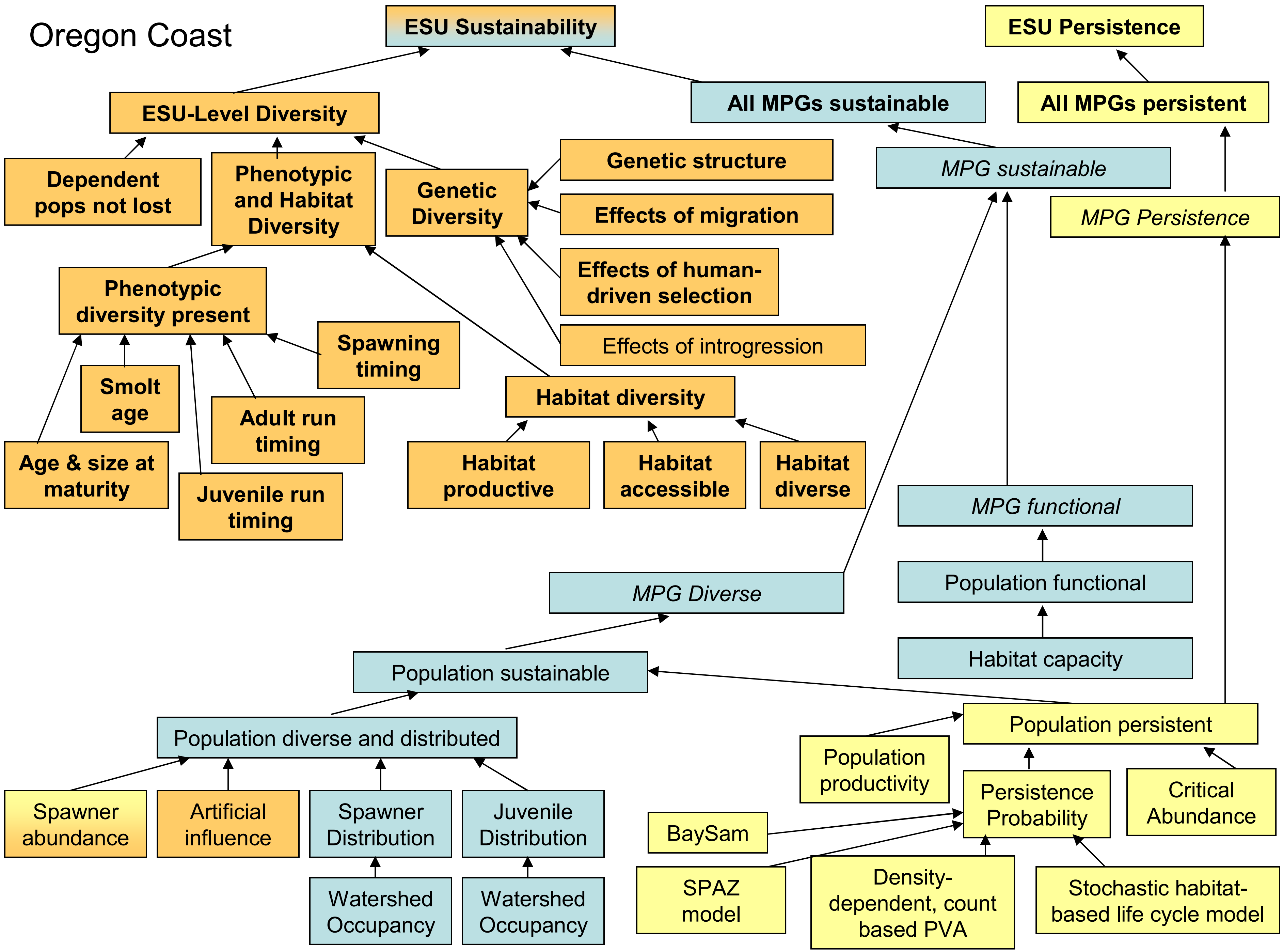



Puget Sound Hood Canal Summer Chum
ESU viability: Each pop. must be viable
Viable abundance range at given productivity
Diversity
PVA
VRAP
Shannon & Simpson indices
Spawning aggregations in all major ecological regions
Spatial structure
Distribution across range
Distance among pops


Willamette/Lower Columbia
ESU viability:
All MPGs must be viable
MPG viability
At least 2 pops arranged so that susceptibility due to catastrophe is minimized
Average risk of all populations
Weighted average of all scores, A&P score are weighted twice of spatial structure and diversity scores
A&P: Average risk level
Probability of persistence from SPAZ
Minimum abundance threshold
Other relevant information
Spatial Structure: Average risk level
% historical habitat currently available
Habitat quality
Habitat connectivity
Risk due to catastrophic event
Diversity: Average risk level
Life history strategies in population
Reduction in variability of traits
Shift in mean of traits
Loss of trait
Stray rate
Change in env. characteristics of occupied habitat
Diversity score for domestication
Harvest rate (adjusted by type)
Mechanisms for adaptation

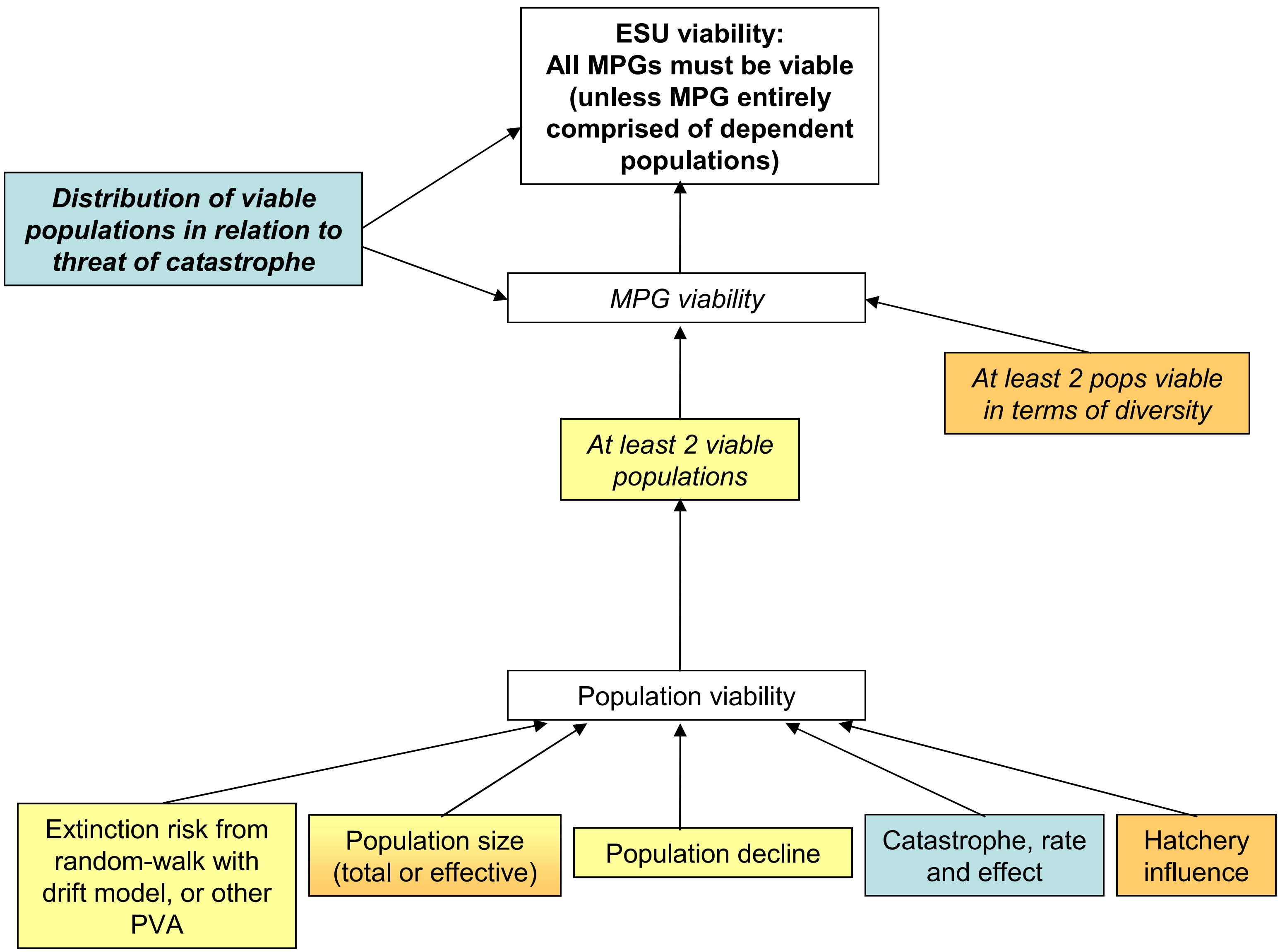
Interior Columbia



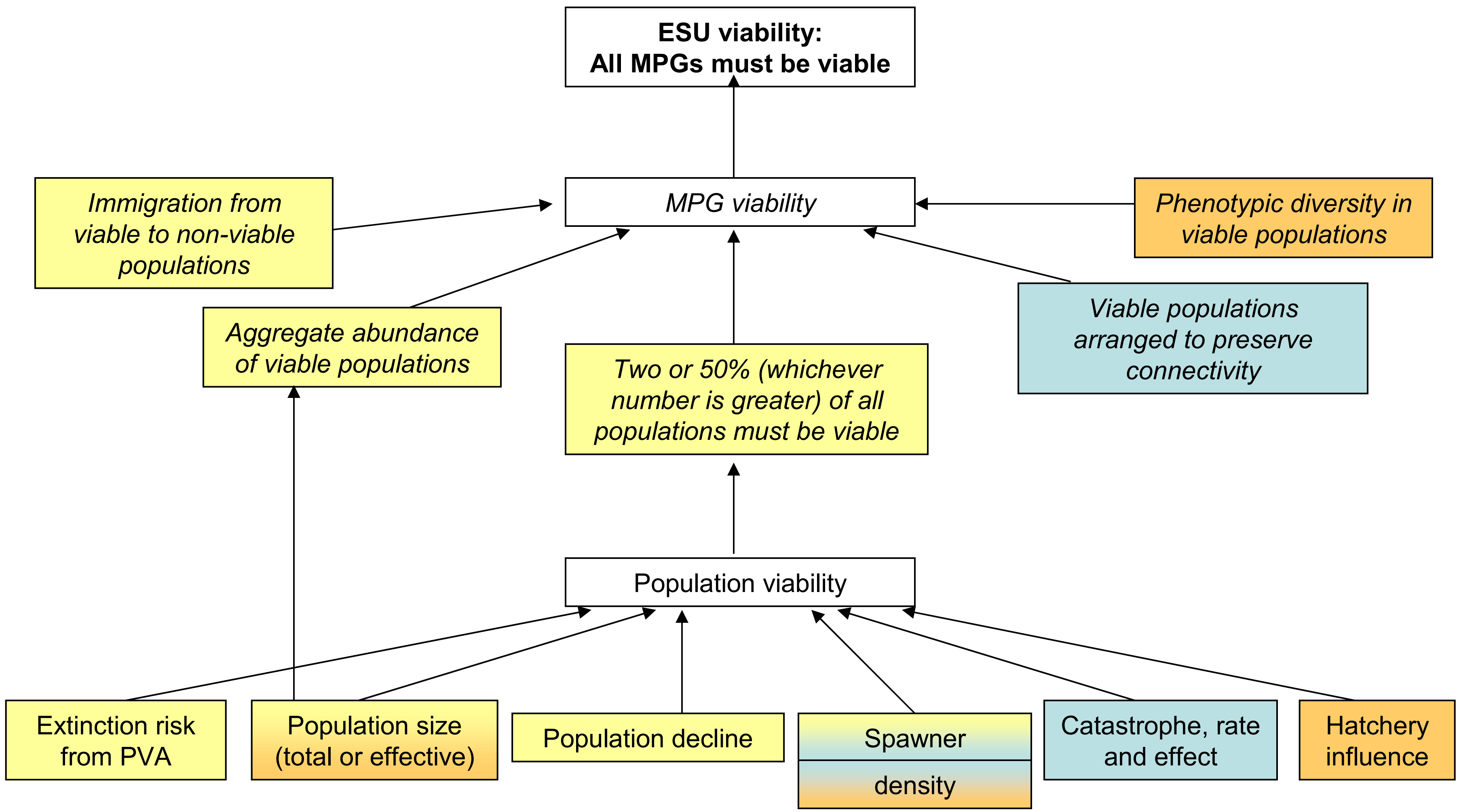


Oregon Coast
ESU Sustainability
ESU Persistence
ESU-Level Diversity
All MPGs sustainable
All MPGs persistent
Dependent pops not lost
Phenotypic and Habitat Diversity
Genetic Diversity
Genetic structure
Effects of migration
Effects of human-driven selection
Effects of introgression
MPG sustainable
MPG Persistence
Phenotypic diversity present
Spawning timing
Smolt age
Adult run timing
Age & size at maturity
Juvenile run timing
Habitat diversity
Habitat productive
Habitat accessible
Habitat diverse
MPG functional
Population functional
Habitat capacity
MPG Diverse
Population sustainable
Population diverse and distributed
Population persistent
Population productivity
Persistence Probability
Critical Abundance
Spawner abundance
Artificial influence
Spawner Distribution
Juvenile Distribution
Watershed Occupancy
Watershed Occupancy
BaySam
SPAZ model
Density-dependent, count based PVA
Stochastic habitat-based life cycle model

Central Valley



Southern Oregon/Northern California Coast
North-Central California Coast



South/South-Central California Coast